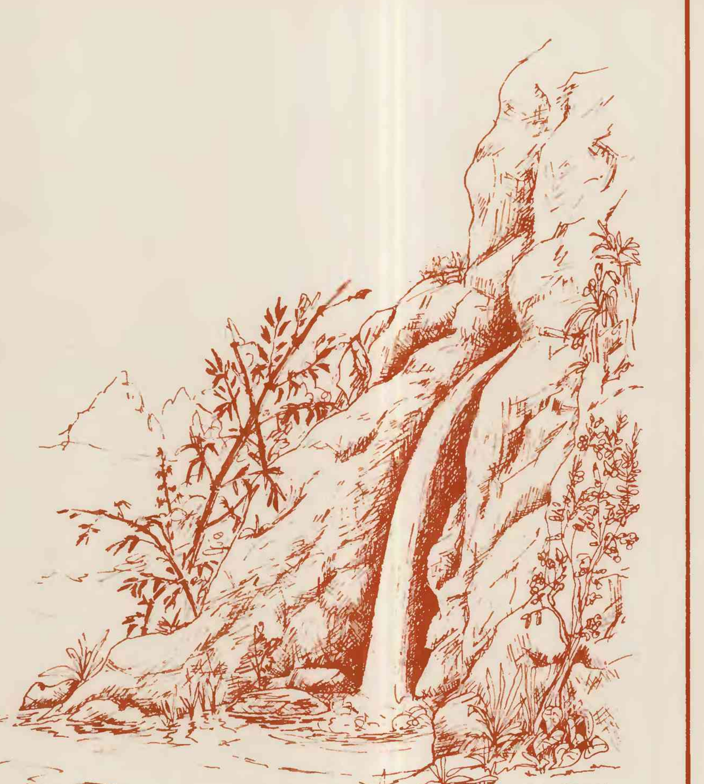
Prepared in cooperation with the
WATER RESOURCES RESEARCH INSTITUTE, UNIVERSITY OF PUERTO RICO
PUERTO RICO DEPARTMENT OF NATURAL RESOURCES
PUERTO RICO LAND ADMINISTRATION

RECONNAISSANCE OF THE PRINCIPAL SPRINGS OF PUERTO RICO, 1982-83



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RECONNAISSANCE OF THE PRINCIPAL SPRINGS OF PUERTO RICO, 1982-83

By
Senén Guzmán-Ríos

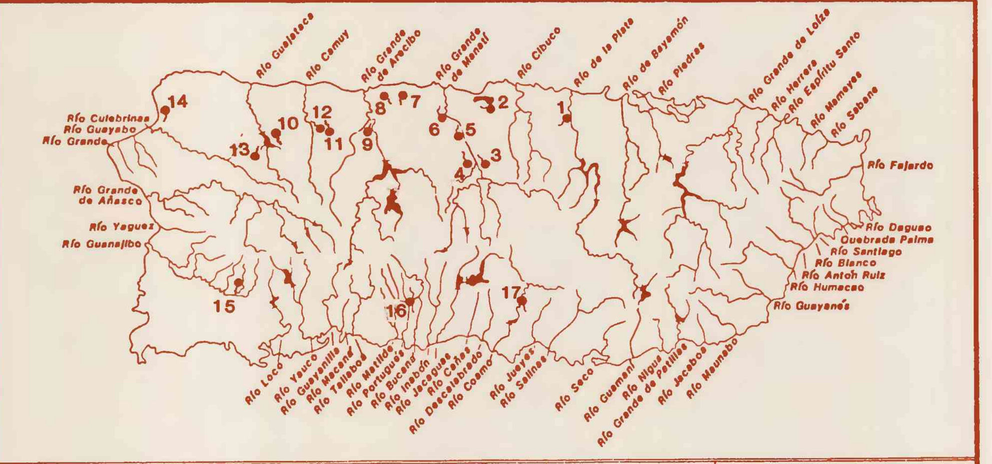
INTRODUCTION

Many springs occur throughout Puerto Rico which discharge fresh and saline water. Most of these are concentrated along the North Coast-Limestone Area **(figure 1)**, but significant ones including some with thermal properties occur along the South Coast of the Island.

Springs occur in many forms and have been classified as to cause, rock structure, discharge, temperature and variability. General categories of springs include volcanic, fissure, depression, contact, artesian and tubular or fracture. Volcanic and fissure springs result from non-gravitational forces. The first are associated with volcanic rocks and the others with fractures extended to great depths in the earth's crust. In both, the temperature exceeds that of the normal local ground-water. Depression, contact, artesian and tubulars are gravity springs which result from water flowing under hydrostatic pressure. In Puerto Rico almost all types of springs occur.

Springs can be an important and valuable water resource. Springflow can be used to supplement surface- and ground-water supplies for industrial and domestic uses. Thermal springs offer a potential for development as tourism and resort attractions. In Puerto Rico, springs are used mostly for limited domestic supplies. Lack of data on the quantity and quality of springflow has limited their potential development. Preliminary investigations of the flow and quality of some springs in Puerto Rico were conducted by Giusti (1978) and Gómez-Gómez and Guzmán-Ríos (1982). The Coamo Thermal Springs (Baños de Coamo) have been developed into a hotel-resort with private and public facilities. However, limited data have also hindered the optimal development of the springs.

In 1982, the U.S. Geological Survey, Water Resources Division initiated a 2-year project to collect baseline data on the flow and chemical properties of the principal springs in Puerto Rico. The project was conducted in cooperation with the Water Resources Research Institute, (University of Puerto Rico), the Puerto Rico Department of Natural Resources, and the Puerto Rico Land Administration. During the first year of the project (October 1982 to June 1983), samples were collected and flows were measured at 17 of the principal springs on the island **(figure 1)**. Samples were collected from ten (10) springs along the north coast, three (3) in the central mountains, two (2) in the west coast, and two (2) in the south coast. The project also included the installation and operation of continuous-recording instruments at the Coamo Thermal Springs (Baños de Coamo) to measure flow, temperature, and specific conductance.



MAP NO.	LATITUDE/ LONGITUDE	NAME	MAP NO.	LATITUDE/ LONGITUDE	NAME
1	182446661555	Maguayo	10	182344665344	Sumbadora
2	182657662506	Ojo de Agua de Vega Baja	11	182410664743	Sonadora
3	182004662638	Torrecillas	12	182359664816	Tiburón
4	182019662853	Represa Sonadora	13	182006665646	Salto Collazo
5	182218662910	Aguas Frias	14	182602670917	Ojo de Agua de Aguadilla
6	182541663136	Ojo de Guillo (el cañito)	15	180543665650	Pozo de la Virgen
7	182825663553	La Cambija	16	180224663642	Baños Quintana
8	182724663920	Zanja Fria	17	180219662225	Baños de Coamo
9	182435664145	San Pedro			

Figure 1.--Principal springs of Puerto Rico.

METHODS AND PROCEDURES

Water samples were collected from the 17 springs as near as possible to each spring opening. Methods described by Wood (1976) were used for the collection of the samples. Total alkalinity as calcium carbonate (CaCO3), pH, temperature, specific conductance, and springflow were measured at the spring site. Raw-water samples were filtered on-site through a 0.45 micron-membrane filter. The samples were then preserved according to procedures described by Brown and others (1970) and shipped to the the U.S. Geological Survey Central Laboratory in Doraville, Georgia, for chemical analyses. Determinations were made of most common ions (Ca, Mg, Na, K, Cl, SO_4, F, SiO_2, Br), trace elements (Al, As, Ba, Be, B, Cd, Cr, Co, Cu, Fe, Pb, Li, Mn, Hg, Mo, Se, Sr, V, Zn) and nutrients (N, NO2, NO3, NH4, P). Samples for dissolved Organic Carbon (DOC) were filtered on site through 0.45 micron silver-membrane filters and placed in special glass containers pre-treated for the collection of organic carbon.

Raw samples for bacteriological analyses were collected in accordance with procedures described by Greeson and others (1971). Incubation following the Membrane Filtration (MF) procedure was begun at the field site within minutes after collection of the samples.

At the Coamo Thermal Springs (Baños de Coamo), a system of three (3) recording-flow meters was installed. Two of the meters were located at the outlets of the public pool area of the springs. The third meter was installed at the inflow to the private pool. The total flow from the springs was computed from the sum of the discharges from the three meters **(figure 2)**. An automatic temperature-specific conductance monitor recorder was installed at the inflow to the private pool. Field tests had shown that the temperature and specific conductance at this point were representative of the outflow from the springs.

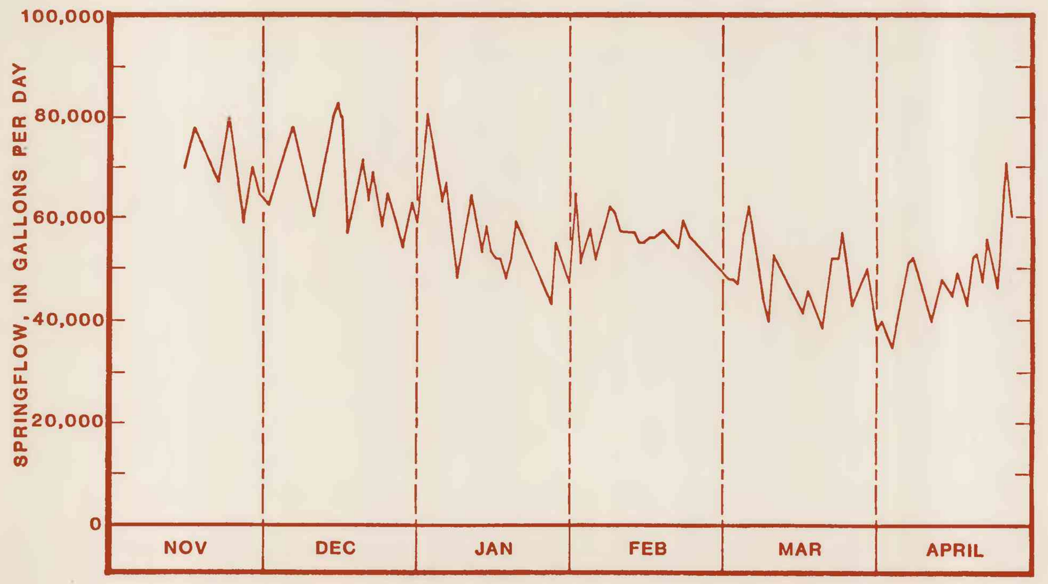


Figure 2.--Hydrograph of Baños de Coamo near Coamo (1982-83).

RESULTS

Data collected during the first year of the project are shown in **tables 1, 3-5**. Concentration values are shown in milligrams per liter (mg/L), or micrograms per liter (ug/L). Specific conductance values are in micromhos per centimeter (umhos/cm); flow in cubic feet per second (ft^3/s) and million gallons per day (Mgal/d); temperature in degrees Celsius (°C) and pH in units. Daily-average flow, temperature, and specific-conductance values for the Coamo Thermal Springs (Baños de Coamo) are shown in **tables 2 and 6**.

Additional information on the stations or data in this report may be available from the U.S. Geological Survey, Water Resources Division, Caribbean District office in San Juan, Puerto Rico (Telephone (809) 753-4414).

REFERENCES

Brown, E., Skougstad, M.W., and Fishman, M.J., 1970, Methods for the collection and analysis of water samples for dissolved minerals and gases: U.S. Geological Survey Techniques of Water Resources Investigations, Book 5, Chapter A1, 160 p.

Giusti, E.V., 1978, Hydrogeology of the karst of Puerto Rico: U.S. Geological Survey Professional Paper 1012, 68 p.

Gómez-Gómez, F., and Guzmán-Ríos, S., 1982, Reconnaissance of ground-water throughout Puerto Rico, September-October 1981: U.S. Geological Survey Open-File Data Report 82-332, 1 p.

Greeson, P.E., and others, 1977, Methods for collection and analysis of aquatic biological and microbiological samples: U.S. Geological Survey Techniques of Water Resources Investigations, Book 5, Chapter A4, 332 p.

Wood, W.W., 1976, Guidelines for collection and field analysis of ground-water samples for selected constituents: U.S. Geological Survey Techniques of Water Resources Investigation, Book 1, Chapter D2, 24 p.

Table 1.--Water discharge at the principal springs throughout Puerto Rico.

SPRING MAP NUMBER	DATE	WATER DISCHARGE FT^3/s (MGD)	SPRING MAP NUMBER	DATE	WATER DISCHARGE FT^3/s (MGD)
1	6 DEC 82	0.52 (0.34)	9	1 DEC 82	16.0 (10.0)
	3 MAR 83	0.40 (0.26)		23 FEB 83	8.40 (5.40)
	28 APR 83	1.70 (1.10)		26 APR 83	12.0 (7.80)
2	30 NOV 82	0.63 (0.41)	10	14 DEC 82	0.24 (0.16)
	3 MAR 83	0.90 (0.58)		2 MAR 83	0.03 (0.02)
	28 APR 83	1.30 (0.84)		27 APR 83	0.10 (0.06)
3	9 DEC 82	0.18 (0.12)	11	7 DEC 82	0.58 (0.37)
	24 FEB 83	0.17 (0.11)		2 MAR 83	0.29 (0.19)
	3 MAY 83	0.19 (0.12)		27 APR 83	0.67 (0.43)
4	30 NOV 82	0.54 (0.35)	12	7 DEC 82	0.58 (0.37)
	2 MAR 83	0.27 (0.17)		2 MAR 83	0.23 (0.15)
	28 APR 83	0.26 (0.17)		27 APR 83	0.36 (0.23)
5	16 DEC 82	10.0 (6.50)	13	1 DEC 82	0.44 (0.28)
	3 MAR 83	10.0 (6.50)		23 FEB 83	0.17 (0.11)
	3 MAY 83	11.0 (7.10)		27 APR 83	0.17 (0.11)
6	30 NOV 82	1.60 (1.10)	14	2 DEC 82	2.10 (1.40)
	2 MAR 83	0.95 (0.61)		23 FEB 83	0.70 (0.45)
	28 APR 83	1.50 (0.97)		28 APR 83	1.00 (0.65)
7	8 DEC 82	9.20 (6.00)	15	2 DEC 82	0.01 (0.01)
	24 FEB 83	9.00 (5.80)		23 FEB 83	0.00 (0.00)
	26 APR 83	9.40 (6.10)		29 APR 83	0.00 (0.00)
8	8 DEC 82	10.0 (6.50)	16	15 DEC 82	0.03 (0.02)
	24 FEB 83	7.30 (4.70)		25 FEB 83	0.01 (0.01)
	26 APR 83	9.30 (6.00)		29 APR 83	0.02 (0.01)
			17	3 DEC 82	0.11 (0.07)
				25 FEB 83	0.06 (0.04)
				29 APR 83	0.09 (0.06)

Table 2.--Specific conductance and temperature at Baños de Coamo Thermal Springs 1983. (Specific conductance in micromhos per centimeter and temperature in degrees Celsius).

DAY	JANUARY		FEBRUARY		MARCH		APRIL		MAY	
	SPECIFIC CONDUCTANCE	TEMPERATURE	SPECIFIC CONCDUCTANCE	TEMPERATURE	SPECIFIC CONDUCTANCE	TEMPERATURE	SPECIFIC CONDUCTANCE	TEMPERATURE	SPECIFIC CONDUCTANCE	TEMPERATURE
1	-	-	2130	43.0	2310	42.6	2270	42.8	2230	38.0
2	-	-	2210	42.7	2320	42.6	2270	42.8	2230	38.0
3	-	-	2300	42.6	2300	42.6	2270	42.8	2230	38.0
4	-	-	2310	42.7	2300	42.6	2270	42.8	2230	38.0
5	-	-	2300	37.7	2310	37.6	2260	37.8	2230	38.0
6	-	-	2300	37.6	2300	37.6	2260	37.8	2230	38.0
7	-	-	2300	37.6	2300	37.6	2260	37.9	2230	38.0
8	-	-	2300	37.7	2300	37.6	2260	37.9	2230	38.0
9	-	-	2300	37.6	2300	37.6	2260	37.9	2230	38.0
10	-	-	2310	37.6	2300	37.6	2260	37.9	2230	38.0
11	-	-	2310	37.6	2300	37.6	2260	37.9	2230	38.0
12	-	-	2310	37.6	2300	37.6	2260	37.9	2230	38.0
13	-	-	2310	37.6	2290	37.7	2250	37.8	2230	37.9
14	-	-	2310	37.6	2290	37.7	2250	37.8	2220	37.9
15	-	-	2310	37.6	2290	37.7	2250	37.8	2220	37.9
16	-	-	2310	37.6	2290	37.7	2250	37.8	2220	38.0
17	-	-	2320	37.6	2290	37.7	2250	37.8	2220	37.9
18	-	-	2300	37.6	2290	37.7	2250	37.8	2220	38.0
19	-	-	2300	37.6	2290	37.7	2250	37.8	2220	38.0
20	-	-	2310	37.6	2290	37.7	2250	37.8	2220	37.9
21	2030	38.1	2320	37.5	2290	37.7	2240	37.8	2220	37.9
22	2020	38.1	2310	37.5	2280	37.7	2240	37.8	2230	37.8
23	2020	38.0	2300	37.6	2280	37.7	2240	37.9	2220	37.8
24	2010	37.8	2300	37.6	2280	37.7	2240	37.9	2220	37.8
25	2050	37.9	2320	37.6	2280	37.8	2240	37.8	-	-
26	2030	37.5	2310	37.6	2280	37.8	2240	37.9	-	-
27	2030	37.6	2320	37.6	2280	37.8	2230	37.9	-	-
28	2030	37.6	2320	37.6	2280	37.8	2230	37.9	-	-
29	2090	37.9	-	-	2280	37.8	2230	38.0	-	-
30	2110	38.0	-	-	2280	37.8	2230	38.0	-	-
31	2100	37.9	-	-	2270	37.8	-	-	-	-

Table 3.--Physical characteristics and common ions at the principal springs throughout Puerto Rico during November-December 1982. Concentrations, in milligrams per liter, unless otherwise indicated

SPRING MAP NUMBER	SPECIFIC CONDUCTANCE Umhos	pH UNITS	TEMPERATURE Deg C	HARDNESS, AS $CaCO_3$	HARDNESS, NONCARBONATE	CALCIUM, DISSOLVED AS Ca	MAGNESIUM, DISSOLVED AS Mg	SODIUM, DISSOLVED AS Na	POTASSIUM, DISSOLVED AS K	ALKALINITY AS $CaCO_3$	SULFIDE, TOTAL AS S	SULFATE, DISSOLVED AS SO_4	CHLORIDE, DISSOLVED AS Cl	FLUORIDE, DISSOLVED AS F	BROMIDE, DISSOLVED AS Br	SILICA, DISSOLVED AS SiO_2	SOLIDS, RESIDUE AT 180° CELSIUS	SOLIDS, SUM OF CONSTITUENTS
1	572	6.7	24.5	250	9	92	5.8	16	1.6	220	<.5	9	32	<.1	<1.0	7.8	303	312
2	860	6.8	24.5	310	57	110	9.5	48	2.4	280	<.5	15	88	.1	.10	9.0	555	437
3	470	7.7	24.0	220	1	82	3.2	8.8	.9	240	<.5	13	13	.1	.10	12	290	264
4	390	7.8	23.0	180	4	70	1.9	6.0	.2	180	<.5	7	9.9	.1	.09	3.6	222	207
5	360	7.7	22.5	160	0	61	2.0	5.4	.5	160	<.5	3	10	.1	.09	5.4	197	186
6	525	6.8	24.0	240	17	93	2.9	12	1.6	250	<.5	4	18	<.1	-	6.4	317	275
7	5470	7.2	24.0	710	460	130	92	930	31	250	<.5	270	1900	.1	1.1	6.3	3360	3510
8	1390	7.2	24.0	320	77	95	19	160	4.9	240	<.5	41	280	<.1	2.5	6.8	788	751
9	430	7.0	23.5	200	0	72	4.8	5.8	1.5	200	<.5	9	8.8	<.1	.09	8.3	216	231
10	465	7.5	23.5	210	3	80	3.1	7.6	1.1	210	<.5	11	14	<.1	.11	5.1	263	248
11	460	7.7	23.5	220	4	84	2.5	7.5	.6	220	<.5	8	13	<.1	.10	5.1	224	251
12	465	7.4	23.5	220	35	85	1.4	7.0	.2	220	<.5	8	11	<.1	.10	4.9	246	231
13	455	7.4	23.0	220	0	84	2.9	4.2	.5	230	<.5	6	6.7	<.1	.09	4.6	237	244
14	540	6.9	25.0	250	0	94	4.5	8.6	.5	250	<.5	7	15	<.1	-	6.2	300	299
15	825	6.8	24.5	460	19	30	93	15	.6	430	<.5	12	26	1.0	.09	49	478	491
16	1520	9.3	31.0	170	150	69	.05	270	1.2	24	<.5	300	250	.4	1.5	26	874	934
17	2250	8.8	43.0	550	530	220	.15	340	2.2	17	<.5	1000	130	1.1	<1.0	30	1860	1750

Table 4.--Trace elements at the principal springs throughout Puerto Rico during November-December 1982. Concentration , in micrograms per liter.

SPRING MAP NUMBER	Al	As	Ba	Be	B	Cd	Cr	Co	Cu	Fe	Pb	Li	Mn	Hg	Mo	Se	Sr	V	Zn
1	10	1	28	<1	20	1	<1	<3	<10	<7	<10	<4	3	<.1	<10	<1	120	<6	<4
2	<10	1	41	<1	30	<1	<1	<3	<10	<3	<10	<4	1	.1	<10	<1	170	<6	5
3	10	<1	24	<1	70	<1	<1	<3	<10	8	<10	5	<1	.1	<10	<1	200	<6	5
4	10	1	9	<1	30	<1	<1	<3	<10	5	<10	4	<1	.1	<10	<1	150	<6	<4
5	50	1	16	<1	70	<1	<1	<3	<10	<3	<10	<4	<1	.4	<10	<1	140	<6	5
6	<10	3	19	<1	30	<1	<1	<3	<10	<3	<10	<4	14	.1	<10	<1	110	9	<4
7	10	<1	24	<1	370	1	<1	<3	<10	9	<10	17	1	.3	<10	<1	860	<6	<4
8	20	1	16	<1	90	<1	<1	<3	<10	8	<10	7	1	.2	<10	<1	210	<6	4
9	30	1	21	<1	10	2	3	<3	<10	19	20	<4	1	.1	<10	<1	330	<6	<4
10	20	1	12	<1	30	<1	<1	<3	<10	<3	<10	<4	<1	<.1	<10	<1	170	<6	<4
11	10	1	12	<1	10	<1	<1	<3	<10	9	<10	<4	<1	.1	<10	<1	110	<6	<4
12	<10	1	12	1	10	1	<1	<3	10	6	10	4	1	<.1	10	<1	110	<6	<4
13	30	1	19	<1	<10	3	3	<3	<10	21	10	<4	<1	.1	<10	<1	700	<6	<4
14	20	1	15	<1	10	<1	3	<3	<10	7	<10	<4	<1	.2	<10	<1	230	<6	<4
15	10	3	79	<1	40	2	3	<3	<10	16	<10	<4	16	.1	10	<1	160	<6	<4
16	50	<1	19	<1	1300	<1	1	<3	<10	4	<10	23	<1	.4	<10	<1	1000	<6	26
17	20	5	32	<1	2500	1	3	<3	<10	24	<10	63	2	.3	<10	.1	1600	<6	<4

Al - Aluminum
As - Arsenic
Ba - Barium
Be - Beryllium
B - Boron
Cd - Cadmium
Cr - Chromium
Co - Cobalt
Cu - Copper
Fe - Iron
Pb - Lead
Li - Lithium
Mn - Manganese
Hg - Mercury
Mo - Molybdenum
Se - Selenium
Sr - Strontium
V - Vanadium
Zn - Zinc

Table 5.--Concentrations of bacteria, principal nutrients, dissolved organic carbon, and cyanide at the principal springs throughout Puerto Rico during November-December 1982. Concentration, in milligrams per liter unless otherwise indicated.

SPRING MAP NUMBER	COLIFORM, FECAL (Colonies/100 mls)	STREPTOCOCCI, FECAL	NITROGEN, AS N	NITROGEN, NITRITE AS N	NITROGEN NO_2+NO_3 AS N	NITROGEN, NH_4 AS N	NITROGEN, NH_4 AS NH_4	NITROGEN, NH_4+ORG N	PHOSPHATE, DISSOLVED AS P	ORGANIC CARBON, DISSOLVED DOC	CYANIDE DISSOLVED AS CN
1	450	320	2.6	<.010	2.5	.08	.10	.10	.02	-	<.01
2	41	58	5.9	<.010	5.6	.15	.19	.30	.02	2.2	<.01
3	72	96	.86	<.010	.66	.05	.06	.20	.04	1.5	<.01
4	20	50	1.2	<.010	.80	<.01	.01	.40	.03	3.0	<.01
5	1800	830	1.4	<.010	1.0	.03	.04	.40	.04	1.8	<.01
6	51	4	3.4	<.010	3.3	.06	.08	.10	.02	1.6	<.01
7	28	100	-	<.010	2.4	.11	.14	<.10	.01	2.0	<.01
8	-	40	-	-	-	-	-	-	-	1.5	<.01
9	380	130	1.4	<.010	1.1	<.01	.01	.30	.06	2.4	<.01
10	380	640	-	-	-	-	-	-	-	2.1	<.01
11	100	240	.90	<.010	.60	.06	.08	.30	.05	-	<.01
12	580	220	-	-	-	-	-	-	-	5.4	<.01
13	100	40	.65	<.010	.45	.03	.04	.20	.01	2.8	<.01
14	74	4	3.1	<.010	2.3	.06	.08	.30	<.01	1.0	<.01
15	1900	1000	.30	<.010	<.10	<.01	.01	.20	.09	2.2	<.01
16	480	850	-	<.010	<.10	.34	.44	<.10	<.01	2.0	<.01
17	4	0	-	<.010	<.10	.31	.40	.60	<.01	2.0	<.01

Table 6.--Daily mean springflow at Baños de Coamo thermal springs, in million gallons per day.

DAY	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	DAY	NOV.	DEC.	JAN.	FEB.	MAR.	APR.
1	-	.063	.068	.065	.048	.040	16	-	.080	.052	.056	.041	.049
2	-	.067	.081	.051	.048	.037	17	.078	.057	.052	.056	.046	.046
3	-	.070	.075	.054	.041	.035	18	.076	.062	.048	.057	.044	.043
4	-	.072	.070	.058	.057	.040	19	.073	.067	.052	.057	.041	.051
5	-	.076	.063	.052	.062	.045	20	.072	.072	.059	.056	.038	.053
6	-	.078	.067	.055	.059	.051	21	.069	.063	.057	.055	.047	.047
7	-	.074	.058	.059	.050	.052	22	.067	.069	.054	.054	.052	.056
8	-	.070	.048	.062	.044	.049	23	.075	.063	.052	.059	.052	.052
9	-	.066	.053	.061	.040	.046	24	.080	.058	.051	.056	.057	.046
10	-	.060	.059	.057	.053	.043	25	.073	.065	.048	.055	.049	.061
11	-	.065	.065	.057	.051	.040	26	.065	.061	.045	.054	.043	.071
12	-	.069	.059	.057	.049	.043	27	.059	.058	.043	.053	.045	.060
13	-	.074	.053	.057	.047	.048	28	.066	.054	.055	.052	.048	-
14	-	.080	.058	.055	.044	.046	29	.070	.058	.053	-	.050	-
15	-	.083	.053	.055	.044	.045	30	.065	.063	.049	-	.043	-
							31	-	.059	.047	-	.038	-